

2425

414 RPL

AD 771052

AD 771052

TECHNICAL REPORT NO. 11830

**TECHNICAL LIBRARY  
REFERENCE COPY**

APPLICATION OF SCAN LASER HEATING  
FOR  
THERMAL IMAGERY NONDESTRUCTIVE TESTING



OCTOBER 1973

20040121185

by GREGORY ARUTUNIAN & OTTO RENIUS

**TACOM**

DISTRIBUTION OF  
THIS DOCUMENT IS UNLIMITED

**MOBILITY SYSTEMS LABORATORY**

**U.S. ARMY TANK AUTOMOTIVE COMMAND Warren, Michigan**

771052



TECHNICAL REPORT NO. 11830

APPLICATION OF SCAN LASER HEATING  
FOR  
THERMAL IMAGERY NONDESTRUCTIVE TESTING

BY

GREGORY ARUTUNIAN  
AND  
OTTO RENIUS

OCTOBER 1973

AMCMS CODE 4931.OM-6350

SCIENCE BRANCH  
RESEARCH, DEVELOPMENT & ENGINEERING DIRECTORATE  
U. S. ARMY TANK AUTOMOTIVE COMMAND  
WARREN, MICHIGAN 48090

The findings in this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

The citation of commercial products in this report does not constitute an official indorsement or approval of such products.

Destroy this report when it is no longer needed. Do not return it to the originator.

## ABSTRACT

Evaluations were made using an infrared non-destructive testing technique employing scan laser heating of the specimen. Thermal images were obtained with a newly developed two-dimensional reflective scanner, coupled to a 50 watt CO<sub>2</sub> laser to irradiate the specimen and a thermal imaging camera to view the specimen's irradiated surfaces. The technique showed a capability of providing a real time non-destructive test for subsurface defects in a variety of materials and structures. It allows the laser heat source and infrared camera to be remotely positioned from the specimen under test, making it possible to examine large specimens.

## TABLE OF CONTENTS

	<u>PAGE NO.</u>
Abstract	i
List of Figures	iii
Introduction	1
Recommendations	3
Summary & Conclusions	4
Equipment Description	5
Test Specimens	8
Experimental Procedure	10
Results	10
References	24
Distribution List	25
DD Form 1473	33

## LIST OF FIGURES

### FIGURE NO.

- 1            50 Watt CO<sub>2</sub> Laser Head
- 2            Schematic of Laser Tube
- 3            Optical Unit of Beam Positioner
- 4            Beam Positioner Control Unit
- 5            Rectangular Scanning Pattern
- 6            Elliptical Scanning Pattern
- 7            Thermal Imaging System
- 8            Laser Safety Equipment
- 9            Arrangement of Simulated Defective Specimen
- 10           Thermal Image of Fiberglass/  
Aluminum Honeycomb
- 11           Thermal Image of Titanium/  
Aluminum Honeycomb
- 12           Thermal Image of Rubber/Aluminum  
Bond

## INTRODUCTION

The basic technique for use of a CO<sub>2</sub> laser to heat a specimen for infrared nondestructive testing was described in TACOM Report No. 11169 dated January 1971, and in the May 1973 issue of Materials Evaluation.

Basically, the technique uses the energy of the scanning high intensity long wavelength laser beam to heat the surface of the specimen under test. A thermal imaging device then views the heated specimen. If the specimen is homogeneous, heat is conducted away from the irradiated surface uniformly after the scanning laser beam has passed. If, however, areas of non-homogeneity exist, the thermal conductance is altered, resulting in surface temperature variations in the specimen. These temperature variations can then be detected by radiometry or thermal imagery and used to locate the defective area of the specimen.

As a result of the initial feasibility investigation reported in 1971, requirements for a reflective laser beam positioner of increased versatility were established. The additional features which were incorporated into the two dimensional scanner used in the evaluations described in this report are:

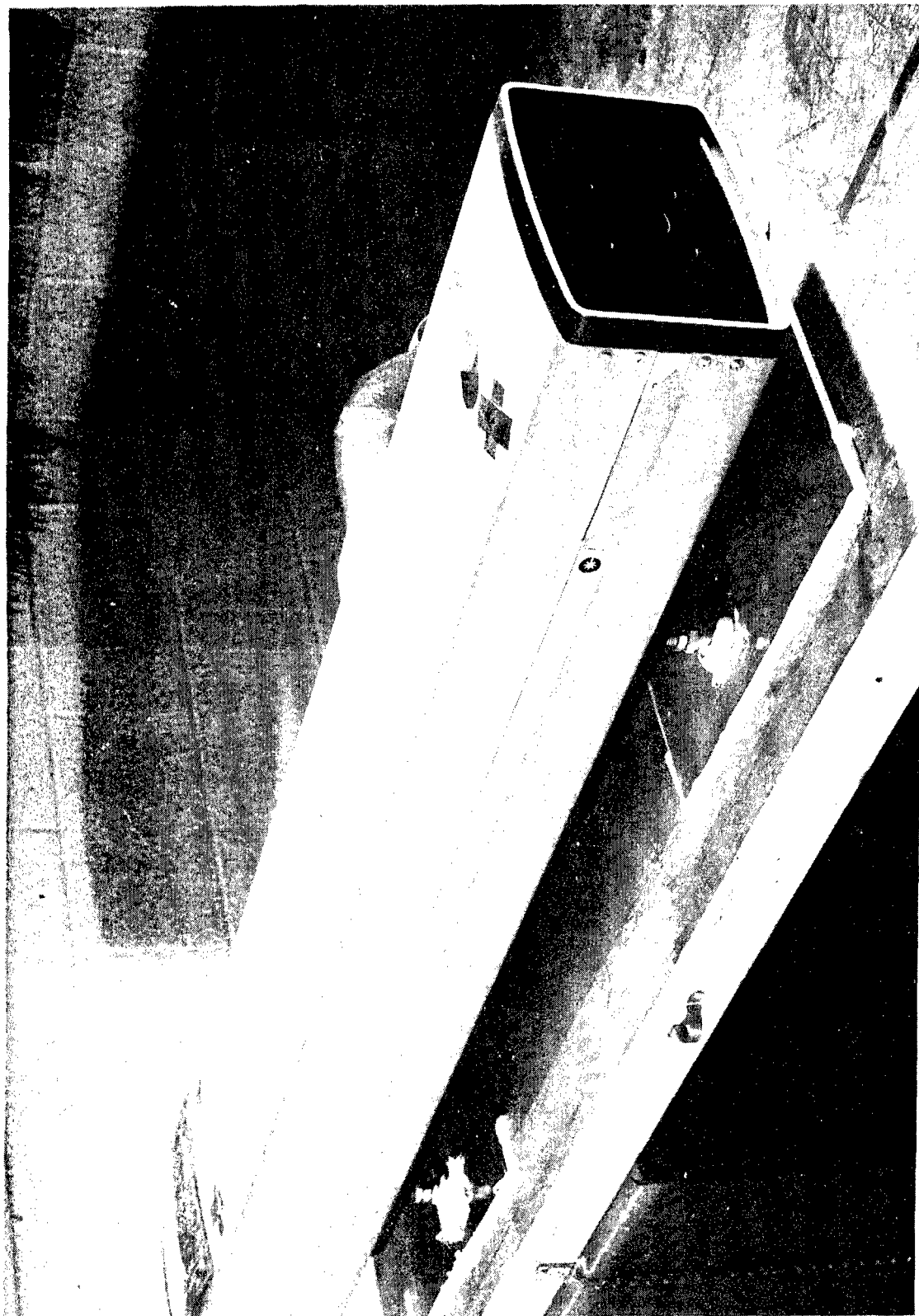
- a. Capability for use of a laser of increased power output
- b. Ability to vary the horizontal scan angle
- c. Ability to vary the vertical scan angle
- d. Incorporation of a beam spot locator
- e. Ability to adjust scanning rate
- f. Capability of varying scan line spacing

These modifications to the original concept of scan-laser specimen heating allowed a 50 watt continuous wave CO<sub>2</sub> laser to be used for heating the specimen's surface. This provided sufficient thermal energy to the specimen under test for thermographic evaluations of sub-surface defects to be made as the laser heating was taking place. It provided in effect a real time nondestructive testing technique for several types of materials and structures.

the skin specimen made it difficult to observe. The bright spot indication of a void faded quickly after the laser beam had passed.

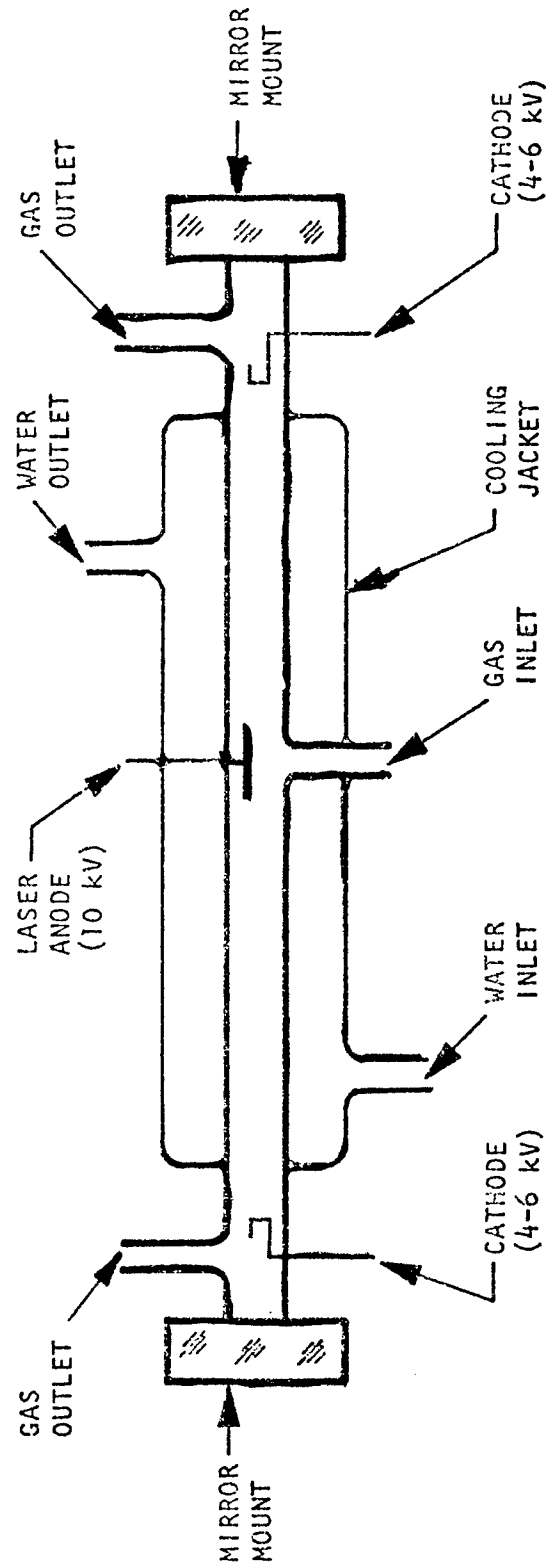
Defective areas of specimens which had a metallic skin bonded to a phenolic or paper honeycomb could not be detected. Similarly, the scan laser method of specimen heating was not effective for outlining voids in solid metal specimens.

Figure 12 is an example of the detection of disbond voids in a specimen of rubber bonded to aluminum. The voids appear hotter than the areas of solid bonding, and are readily detected under a wide variety of scanning conditions.



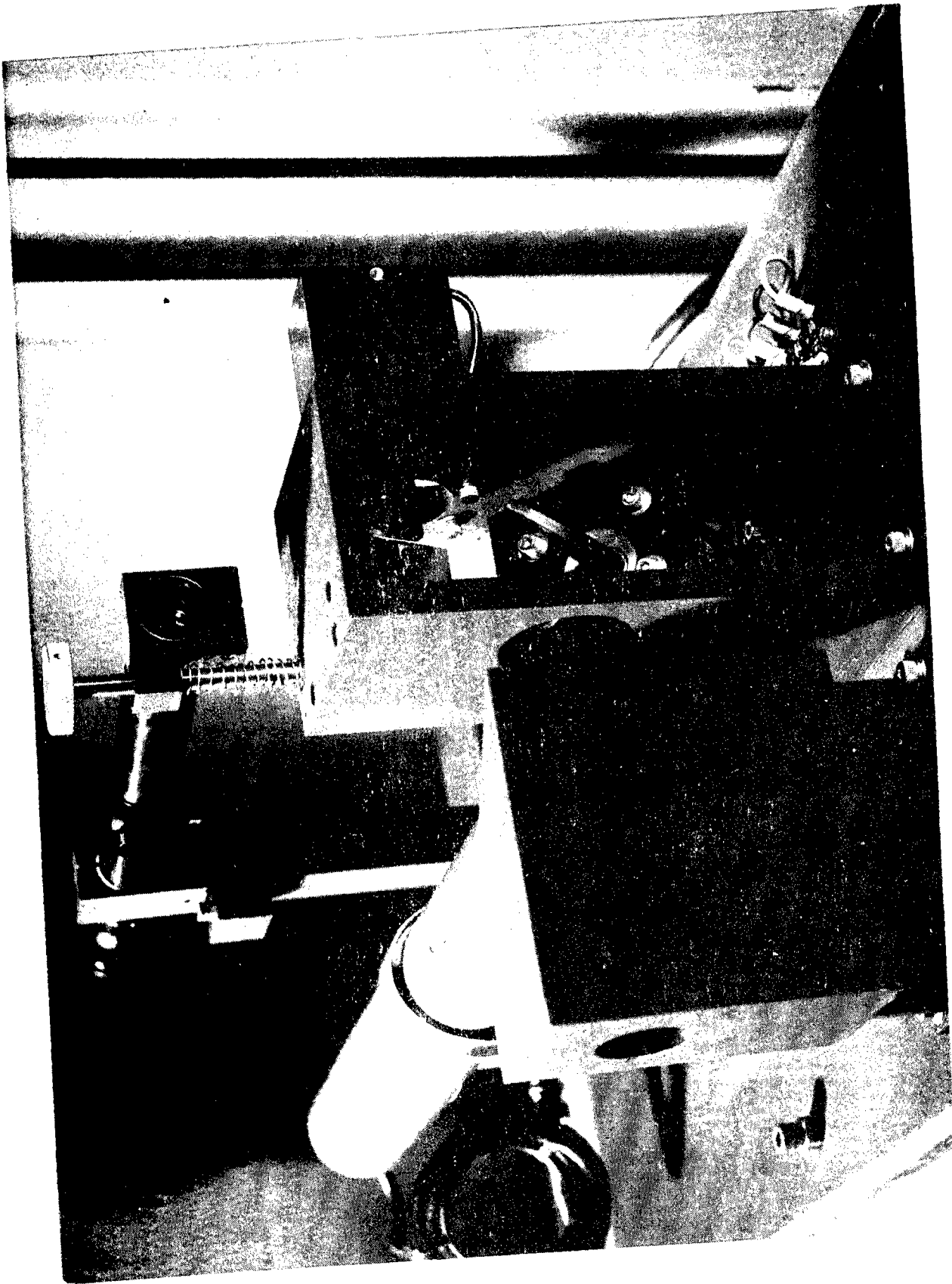
50 Watt CO<sub>2</sub> Laser Head

FIGURE 1



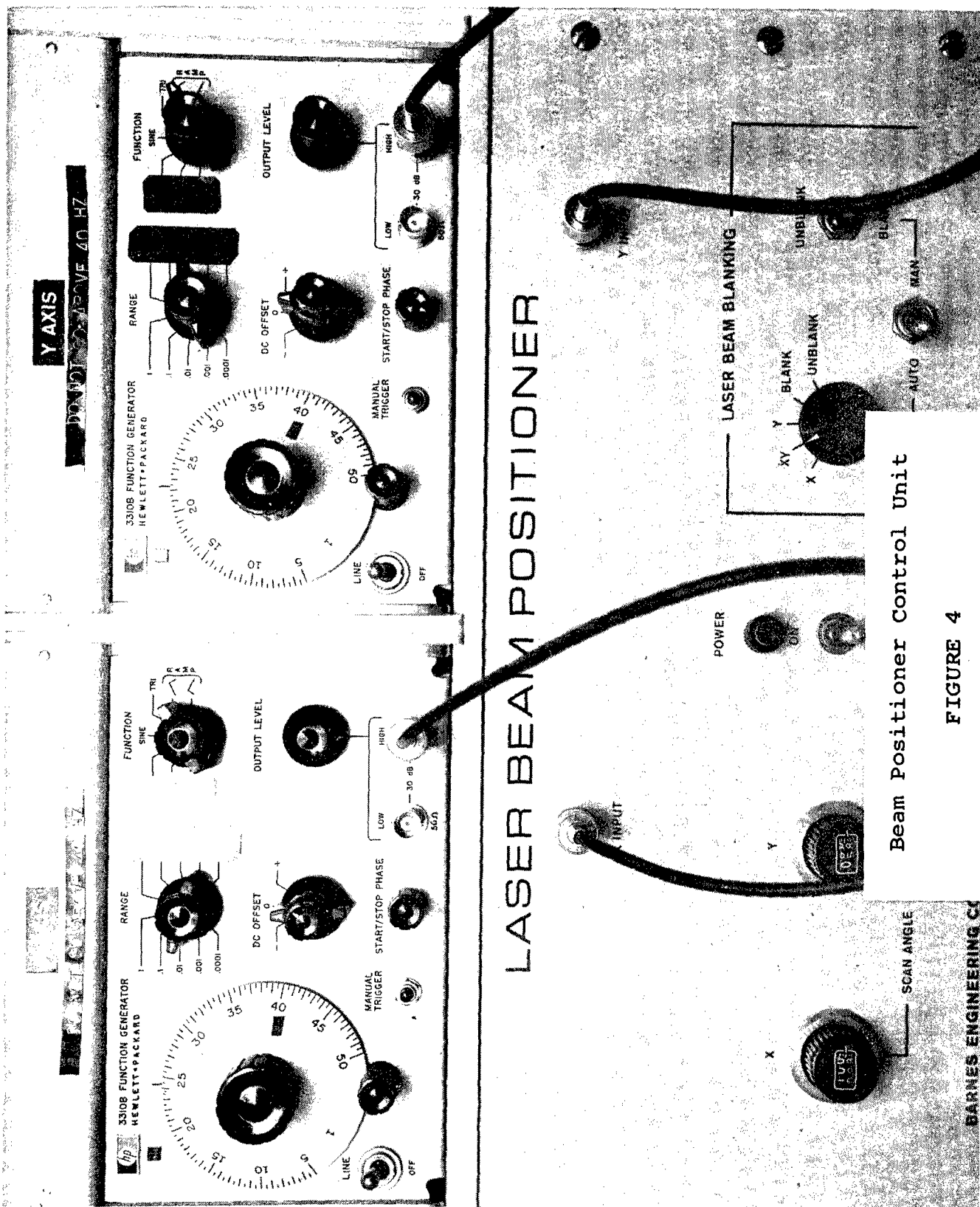
Schematic of Laser Tube

FIGURE 2



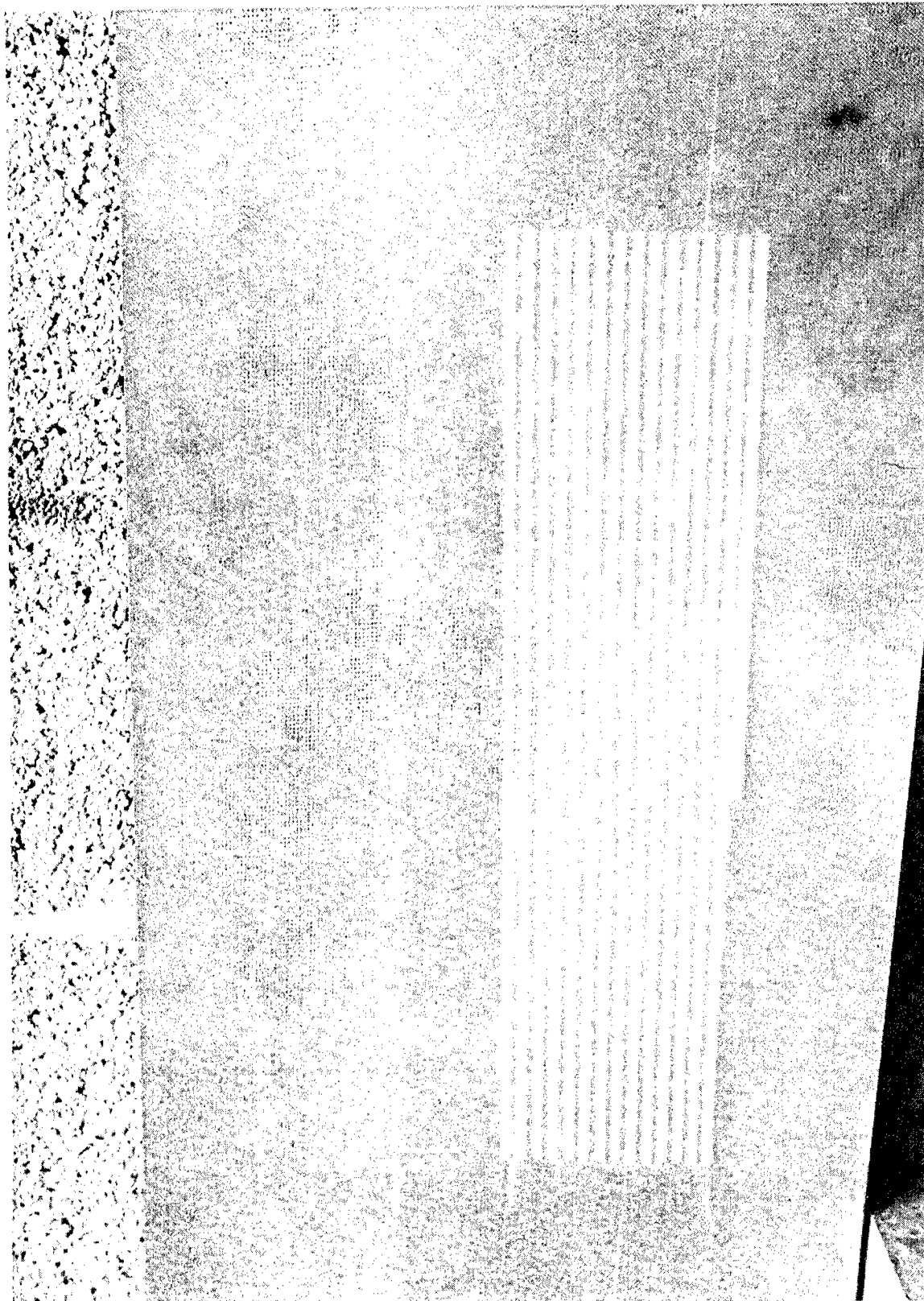
Optical Unit of Beam Positioner

FIGURE 3



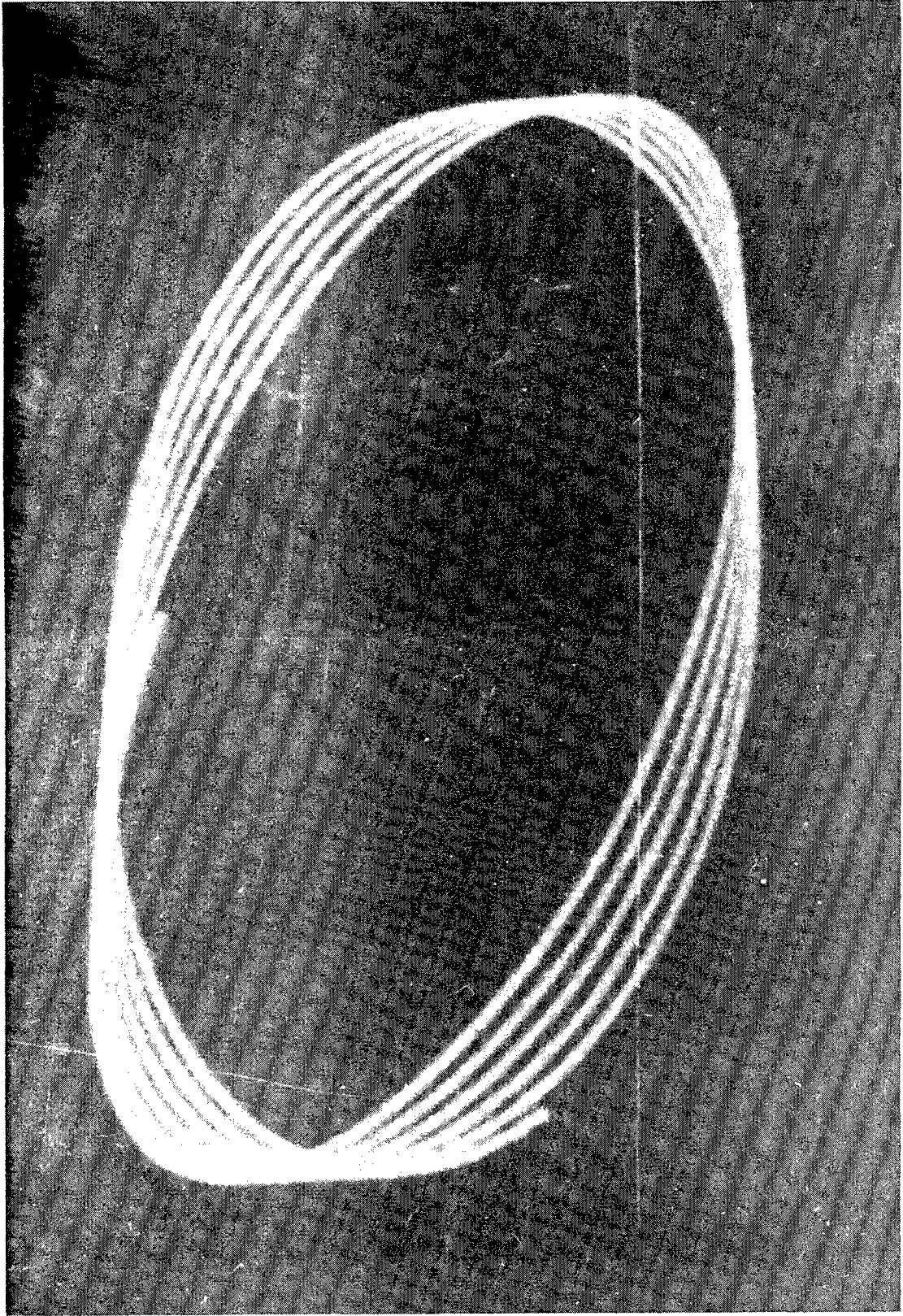
Beam Positioner Control Unit

FIGURE 4



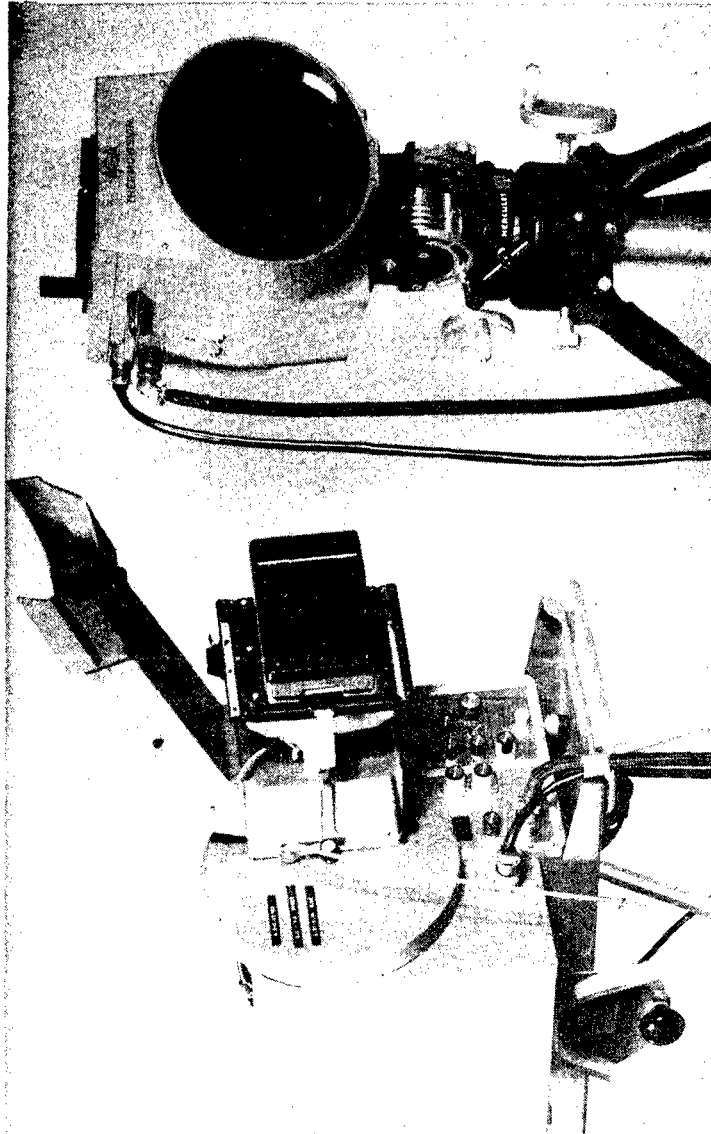
Rectangular Scanning Pattern

FIGURE 5



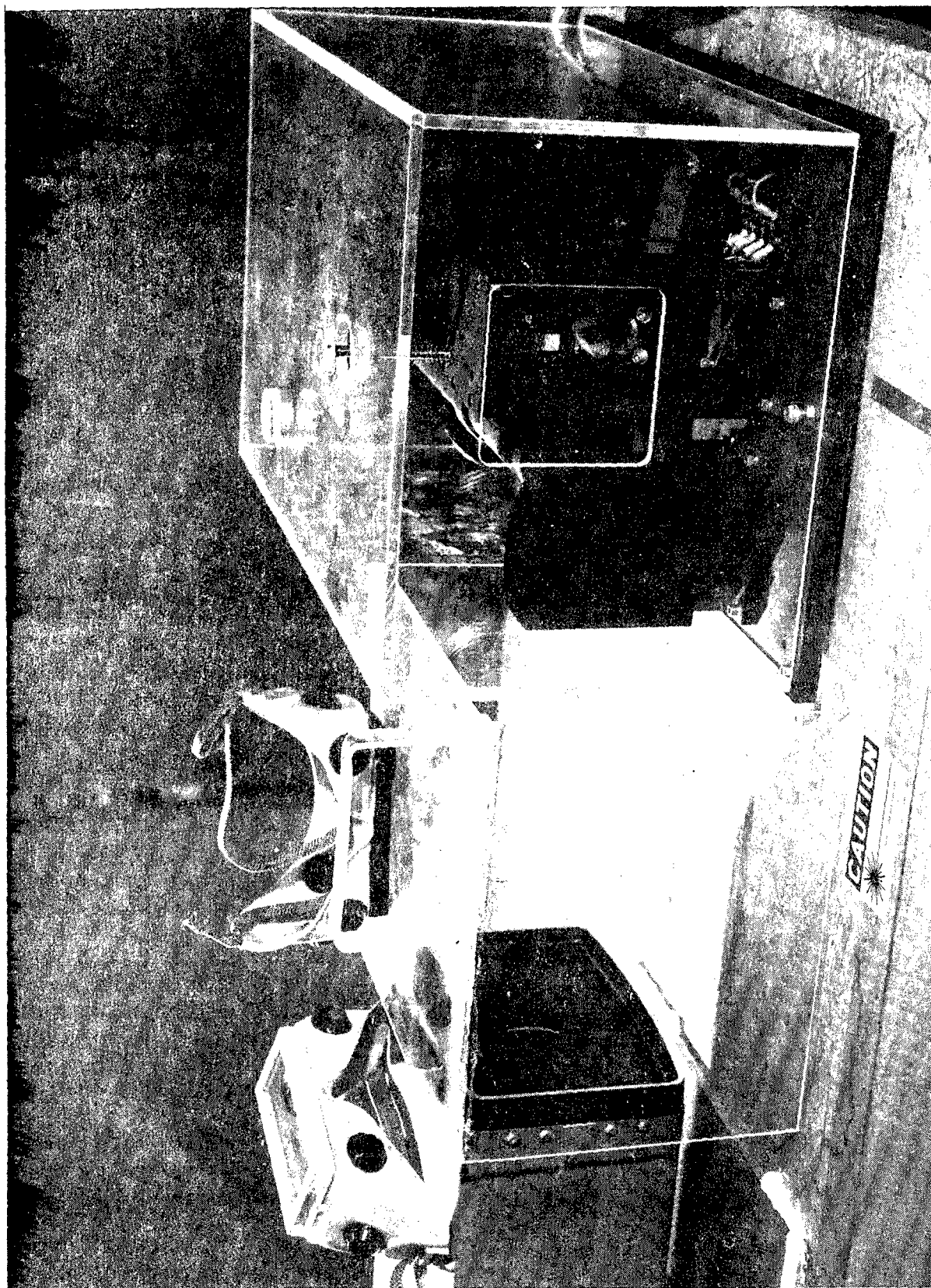
Elliptical Scanning Pattern

FIGURE 6



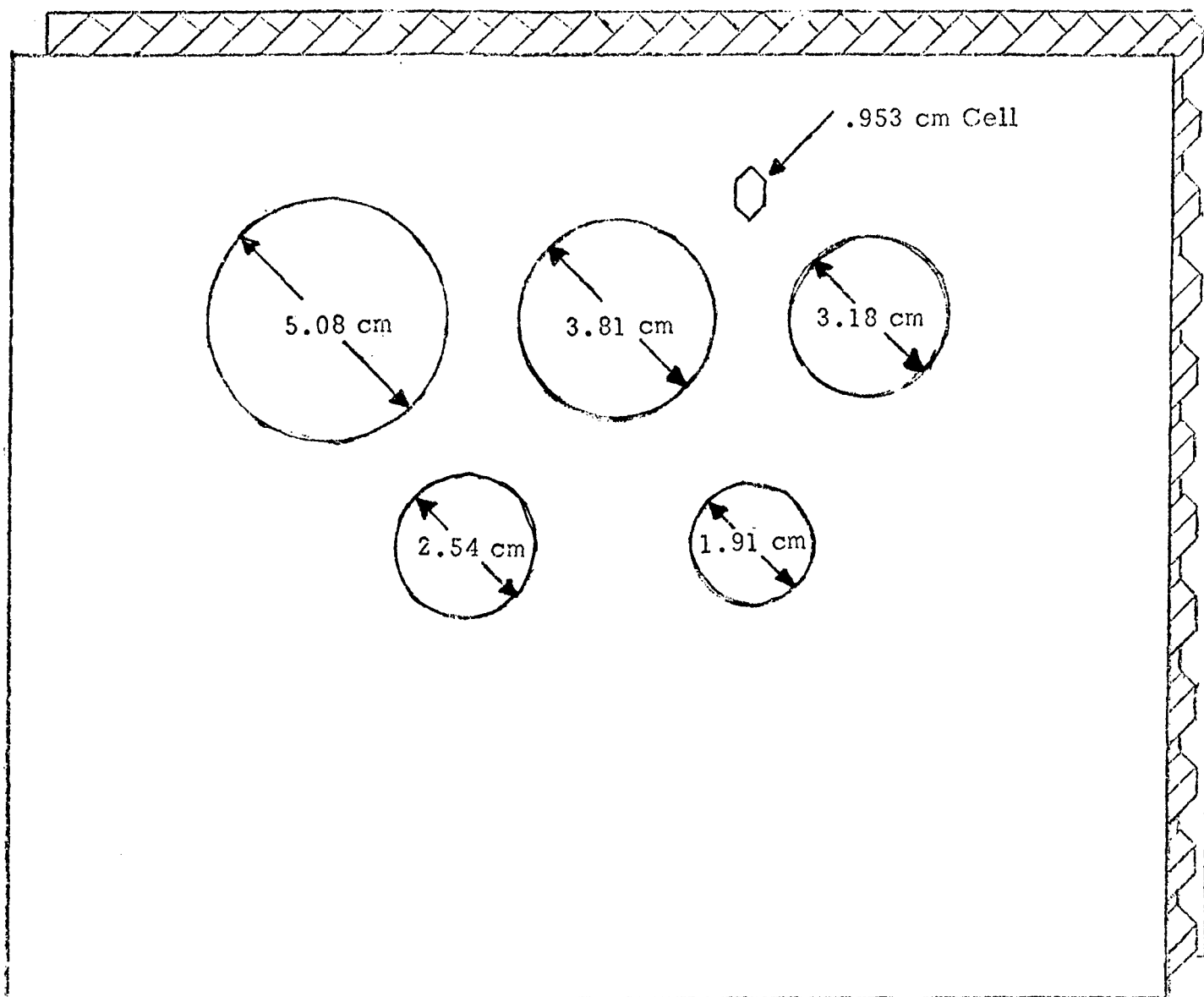
Thermal Imaging System

FIGURE 7



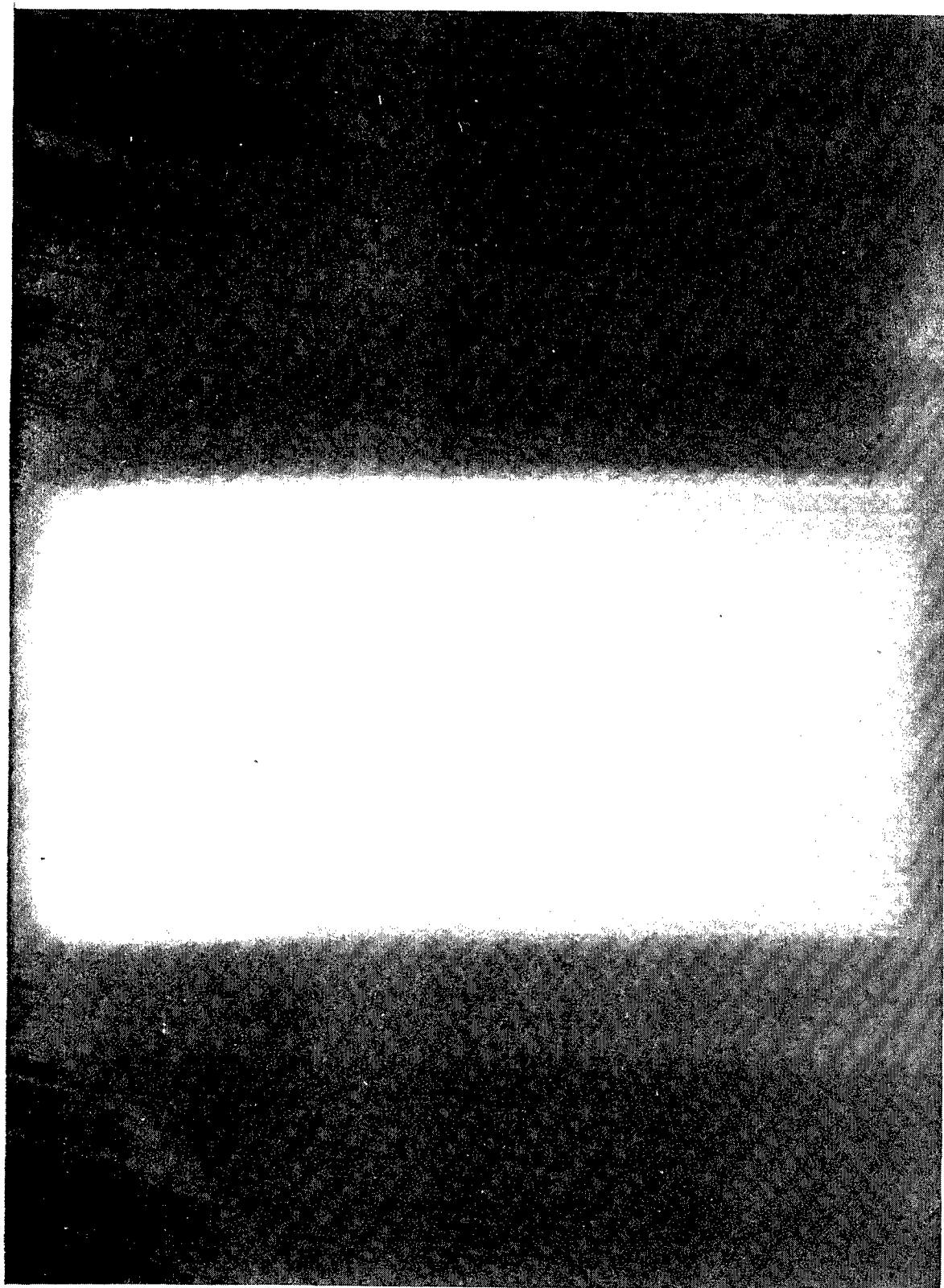
Laser Safety Equipment

FIGURE 8



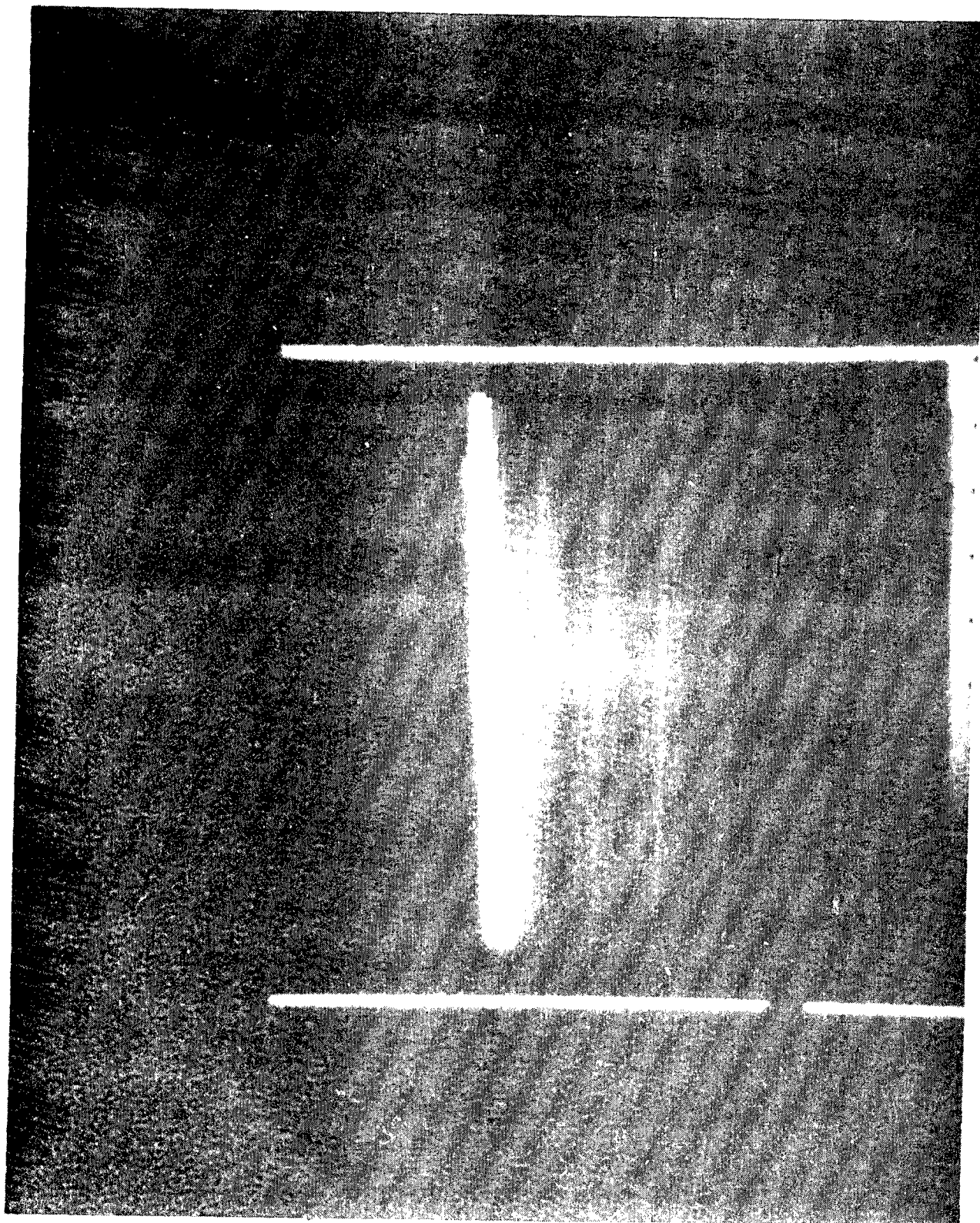
Arrangement of Simulated  
Defective Specimen

FIGURE 9



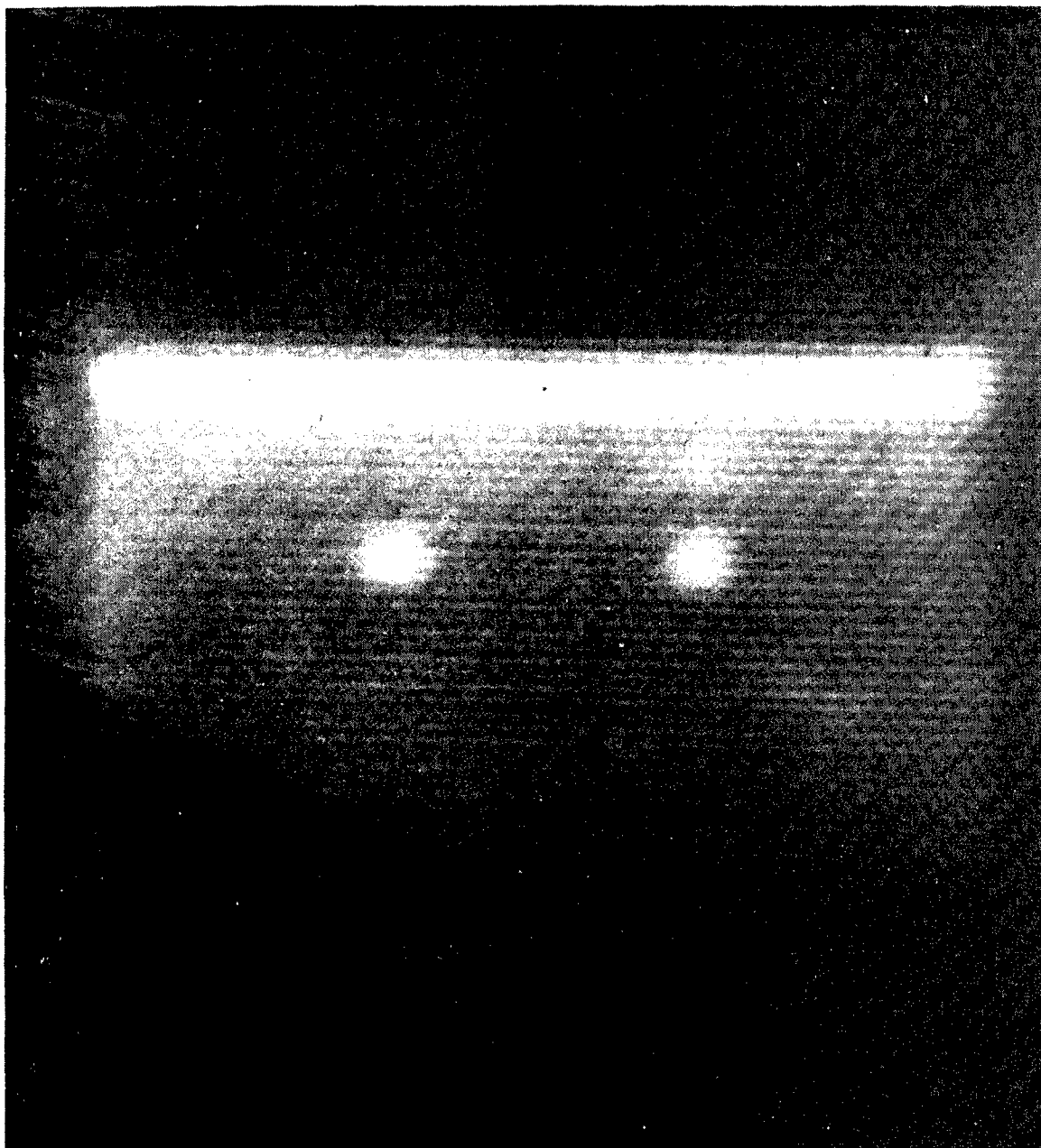
Thermal Image of Fiberglass/  
Aluminum Honeycomb

FIGURE 10



Thermal Image of Titanium/  
Aluminum Honeycomb

FIGURE 11



Thermal Image of Rubber/  
Aluminum Bond

FIGURE 12

### REFERENCES

1. "Laser Illumination for Infrared Nondestructive Testing" by Otto Renius, Materials Evaluation, May 1973.
2. "Investigation of a Laser Illuminator-Thermal Imaging System for the Detection of Voids and Disbonds" U.S. Army TACOM, Report # 11169, January 1971.
3. "Application of Infrared Inspection Techniques to the Inspection of Artillery Shells for Unseated Rotating Bands and Improperly Processed Mechanical Joints" unpublished paper presented by J. Pasman, Picatinny Arsenal at 1970 Materials Testing Meeting, Watertown, Massachusetts.
4. "Infrared Nondestructive Testing Techniques in which a Scanning CO<sub>2</sub> Laser Heat Source is Used" WECOM Report RE 70-159.
5. "Infrared Physics and Engineering" Jamieson et al McGraw-Hill 1963.

# DISTRIBUTION LIST

<u>ADDRESSEE</u>	<u>NO. OF COPIES</u>
Commander	
U.S. Army Tank Automotive Command	
ATTN: RD&E Dir, AMSTA-R	1
System Dev Div, Tactical Trk Br, AMSTA-REK	1
Prop Sys Lab, Diagnostic Equip Func, AMSTA-RGD	1
Armor, Mat & Comp Div, Materials Br, AMSTA-RKM	10
Tech Data Div, Specs Sec, AMSTA-RSES	1
Wheeled Veh Sec, AMSTA-RSEW	1
Mob Sys Lab, Veh Locomotion Sec, AMSTA-RURV	1
Frame, Sus & Track Br, AMSTA-RUT	1
Track, R&E Sec, AMSTA-RUTT	1
Mat'l Mgmt Dir (NICP), AMSTA-FCGA	1
Maintenance Dir (NMP), Maint Mgmt Div, AMSTA-MOE	1
Product Assurance Dir, Quality Engr Div, AMSTA-QE	1
Product Managers	
GOER, AMCPM-GOR	1
M561/XM705 Trk, AMCPM-GG	1
MICV, AMCPM-MCV	1
ARSV, AMCPM-RSV	1
Liaison Offices	
USAECOM, AMSEL-RD-LN	1
USAWECOM, AMSWE-ICV	1
USACDC Ln Ofc, AMXMD-PDS	1
Canadian Forces Ln Ofc, CDLS-D	1
USMC Ln Ofc, USMC-LNU	1
Commander	1
Defense Metals Information Center	
505 King Ave	
Battelle Memorial Institute	
Columbus, Ohio 43201	
Commander	20
Defense Documentation Center	
Cameron Station	
Alexandria, VA 22314	
Office of Chief of Research & Development	
Department of the Army	
ATTN: CRDPES	1
Washington, DC 20310	

<u>ADDRESSEE</u>	<u>NO. OF COPIES</u>
Commander Army Research Office Box CM Duke Station Durham, North Carolina 27706	1
Commander U.S. Army Materiel Command ATTN: AMCQA	1
AMCQA-E	2
AMCQA-P	2
AMCRD-TC	1
AMCRL	1
AMCRD-EA	1
AMCRD-T&E	1
AMCRP-PIP	1
5001 Eisenhower Avenue Alexandria, VA 22304	
Commander US Army Electronics Command ATTN: AMSEL-CB	2
AMSEL-PP-PO	1
AMSEL-MW	1
AMSEL-RD-GT	1
AMSEL-PA-C	1
Fort Monmouth, NJ 07703	
Commander US Army Missile Command ATTN: AMSMI-RBLD	2
AMSMI-RKK	1
AMSMI-RSM	1
AMSMI-RTR	1
AMSMI-Q	2
AMSMI-M	1
Redstone Arsenal, Alabama 35809	
Commander USA Mobility Equipment Command 4300 Goodfellow Boulevard ATTN: AMSME-Q	1
AMSME-QP	1

<u>ADDRESSEE</u>	<u>NO. OF COPIES</u>
ATTN: AMSME-QE	1
AMSME-QR	1
AMSME-M	1
AMSME-P	1
AMSME-R	1
St. Louis, Missouri 63166	
Commander	
US Army Munitions Command	
ATTN: AMSMU-CE, Mr. R. Schwartz	1
AMSMU-Q, Mr. W. Thomas	2
AMSMU-RE, Mr. C. Staley	1
Dover, NJ 07801	
Commander	
US Army Natick Laboratories	
ATTN: AMXRE-QE	1
AMXRE-GE	1
Kansas Street	
Natick, Massachusetts 10760	
Commander	
USA Test & Evaluation Command	
ATTN: AMSTE-TA-A	2
Aberdeen Proving Ground, MD 21005	
Commander	
US Army Armament Command	
ATTN: AMSWE-RET	1
AMSWE-PPR	1
AMSWE-QA	3
Rock Island, Illinois 61202	
Commander	
Aberdeen Proving Ground, MD 21005	
ATTN: STEAP-MT, Mr. J. M. McKinley	1
STEAP-TL	1
Commander	
Edgewood Arsenal	
ATTN: SMUEA-TSP	1
SMUEA-QAE	1
SMUEA-QAI	1
SMUEA-QAP	1
SMUEA-QAIP	1
Edgewood, MD 21010	

<u>ADDRESSEE</u>	<u>NO. OF COPIES</u>
Commander Fort Detrick ATTN: Plans & Readiness Operations Ofc Frederick, MD 21701	2
Commander Frankford Arsenal ATTN: SMUFA-P3300	1
SMUFA-C2500	1
SMUFA-Q1000	1
SMUFA-Q2100	2
SMUFA-N3100-202-1, Mr. E. Roffman	1
SMUFA-Q6120-64-1, Mr. W. Shebest	1
SMUFA-Q6130-64-1, Mr. S. Sitelman	1
SMUFA-A2000	1
SMUFA-F6000	2
Philadelphia, PA 19137	
Commander Harry Diamond Laboratories Connecticut Ave & Van Ness Street, NW Washington, DC 20438	1
Commander Picatinny Arsenal ATTN: SMUPA-RT-S	1
SMUPA-VA6, Mr. H. DeFazio	1
SMUPA-VC2, Mr. T. M. Roach, Jr.	1
SMUPA-VG, Mr. A. Clear	1
SMUPA-ND 1, Mr. D. Stein	1
Dover, NJ 07801	
Commander Rock Island Arsenal ATTN: 9320, Research & Development	1
SWERI-PPE	1
SWERI-QA	2
SWERI-RDL	1
SWERI-PPQ	1
SWERI-PPR	1
Rock Island, ILL 61201	

<u>ADDRESSEE</u>	<u>NO. OF COPIES</u>
Commander USA Aeronautical Depot Maintenance Center ATTN: SSMAC-Q Corpus Christi, Texas 78419	1
Commander USA Ammunition Procurement & Supply Agency ATTN: SMUAT-E Joliet, Illinois 60436	2
Technical Director USA Coating-Chemical Laboratory Aberdeen Proving Ground, MD 21005	1
Commander USA Mobility Equip Rsch & Dev Center ATTN: Tech Documents Center, Bldg 315	
SMEFB-P	1
SMEFB-M	1
SMEFB-X	1
SMEFB-A	1
SMEFB-B	1
SMEFB-H	1
SMEFB-J	1
SMEFB-F	1
SMEFB-MM	1
SMEFB-Q	1
SMEFB-QQ	1
SMEFB-QE, Mr. Jacob K. Mauzy	1
Ft Belvoir, VA 22060	
Commander Watervliet Arsenal ATTN: SWEWV-QA, Mr. J. Penrose	1
SWEWV-QA, Quality Assurance Ofc	1
Watervliet, NY 12189	
Commander Anniston Army Depot ATTN: AMXAN-QA	1
Anniston, Alabama 36202	

<u>ADDRESSEE</u>	<u>NO. OF COPIES</u>
Commander Atlanta Army Depot ATTN: AMXAT-CSQ Forest Park, GA 30050	1
Commander Letterkenny Army Depot ATTN: AMXLE-CQ AMXLE-NSQ Chambersburg, PA 17201	1 1
Commander Lexington-Bluegrass Army Depot ATTN: AMXLX-QA Lexington, KY 40507	1
Commander New Cumberland Army Depot ATTN: AMXNC-256 New Cumberland, PA 17070	1
Commander Pueblo Army Depot ATTN: AMXPU-BF Pueblo, Colorado 81001	1
Commander Red River Army Depot ATTN: AMXRR-QAO Texarkana, Texas 75502	1
Commander Sacramento Army Depot ATTN: AMXSA-QA Sacramento, CA 95801	1
Savanna Army Depot ATTN: AMXSV-QAO Savanna, Illinois 61074	1
Commander Seneca Army Depot ATTN: AMXSE-AXI Romulus, NY 14541	1

<u>ADDRESSEE</u>	<u>NO. OF COPIES</u>
Commander Sharpe Army Depot ATTN: AMXSH-CQ Lathrop, California 95330	1
Commander Sierra Army Depot ATTN: AMXSI-QA Herlong, CA 96113	1
Commander Tobyhanna Army Depot ATTN: AMXTO-Q Tobyhanna, PA 18466	1
Commander Tooele Army Depot ATTN: AMXTE-QAD Tooele, Utah 84074	1
Commander Umatilla Army Depot ATTN: AMXUM-QA Hermiston, Oregon 97838	1
Chief Bureau of Naval Weapons Department of the Navy Washington, DC 20390	1
Chief Bureau of Ships Department of the Navy Washington, DC 20315	1
Director Naval Research Laboratory Anacostia Station Washington, DC 20315	1
Commander Wright Air Development Division ATTN: ASRC Wright-Patterson AFB, Ohio 45433	2

<u>ADDRESSEE</u>	<u>NO. OF COPIES</u>
Director	
Army Materials & Mechanics Research Center	
ATTN: AMXMR-STL	5
AMXMR-M	2
AMXMR-P	1
AMXMR-ET, Mr. Valente/Mr. Hatch	2
AMXMR-MQ	2
AMXMR-MS	1
Watertown, Massachusetts 02172	
Commander	
US Army Aviation Systems Command	
ATTN: AMSAV-R-R	1
AMSAV-R-EGE	1
AMSAV-A-L	1
AMSAV-LE	1
AMSAV-A-LV	1
AMSAV-A-V	1
St. Louis, Missouri 63166	
Director	
US Army Production Equipment Agency	
ATTN: AMLPE-MT	1
Rock Island, Illinois 61201	
Commander	
Wright Patterson AFB	
ATTN: ASSDL-FEM	2
ASRCMP-1	1
Wright Patterson AFB, Ohio 40204	
Department of Commerce	
Institution for Applied Technology	4
Office of Vehicle Systems Research	
Washington, DC 20234	

UNCLASSIFIED

Security Classification

## DOCUMENT CONTROL DATA - R &amp; D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Physics Function, Science Branch US Army Tank Automotive Command Warren, Michigan 48090		2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	
3. REPORT TITLE Application of Scan Laser Heating For Thermal Imagery Nondestructive Testing		2b. GROUP	
4. DESCRIPTIVE NOTES (Type of report and inclusive dates)			
5. AUTHOR(S) (First name, middle initial, last name) Arutunian, Gregory Renius, Otto			
6. REPORT DATE October 1973		7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
8a. CONTRACT OR GRANT NO.		9a. ORIGINATOR'S REPORT NUMBER(S) 11830	
b. PROJECT NO.		9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
c. AMCMS 4931.OM.6350			
d.			
10. DISTRIBUTION STATEMENT (1) Distribution of this document is unlimited.			
11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY U.S. Army Tank Automotive Command	
13. ABSTRACT Evaluations were made using an infrared non-destructive testing technique employing scan laser heating of the specimen. Thermal images were obtained with a newly developed two-dimensional reflective scanner, coupled to a 50 watt CO <sub>2</sub> laser to irradiate the specimen and a thermal imaging camera to view the specimen's irradiated surfaces. The technique showed a capability of providing a real time non-destructive test for subsurface defects in a variety of materials and structures. It allows the laser heat source and infrared camera to be remotely positioned from the specimen under test, making it possible to examine large specimens.			

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT

**INSTRUCTIONS TO FILL OUT DD FORM 1473 - DOCUMENT CONTROL DATA**  
(See ASPR 4-211)

1. **ORIGINATING ACTIVITY:** Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization (*corporate author*) issuing the report.

2a. **REPORT SECURITY CLASSIFICATION:** Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. **GROUP:** Automatic downgrading is specified in DoD directive 5200.10 and Armed Forces Industrial Security Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. **REPORT TITLE:** Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. **DESCRIPTIVE NOTES:** If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. **AUTHOR(S):** Enter the name(s) of the author(s) in normal order, e.g., full first name, middle initial, last name. If military, show grade and branch of service. The name of the principal author is a minimum requirement.

6. **REPORT DATE:** Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7a. **TOTAL NUMBER OF PAGES:** The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. **NUMBER OF REFERENCES:** Enter the total number of references cited in the report.

8a. **CONTRACT OR GRANT NUMBER:** If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, and 8d. **PROJECT NUMBER:** Enter the appropriate military department identification, such as project number, task area number, systems numbers, work unit number, etc.

9a. **ORIGINATOR'S REPORT NUMBER(S):** Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. **OTHER REPORT NUMBER(S):** If the report has been assigned any other report numbers (*either by the originator or by the sponsor*), also enter this number(s).

10. **DISTRIBUTION STATEMENT:** Enter the one distribution statement pertaining to the report.

**Contractor-Imposed Distribution Statement**

The Armed Services Procurement Regulations (ASPR), para 9-203 stipulates that each piece of data to which limited rights are to be asserted must be marked with the following legend:

"Furnished under United States Government Contract No. \_\_\_\_\_. Shall not be either released outside the Government, or used, duplicated, or disclosed in whole or in part for manufacture or procurement, without the written permission of \_\_\_\_\_, except for:  
(i) emergency repair or overhaul work by or for the Government, where the item or process concerned is not otherwise reasonably available to enable timely performance of the work; or (ii) release to a foreign government, as the interests of the United States may require; provided that in either case the release, use, duplication or disclosure hereof shall be subject to the foregoing limitations. This legend shall be marked on any reproduction hereof in whole or in part."

If the above statement is to be used on this form, enter the following abbreviated statement:

"Furnished under U. S. Government Contract No. \_\_\_\_\_. Shall not be either released outside the Government, or used, duplicated, or disclosed in whole or in part for manufacture or procurement, without the written permission of \_\_\_\_\_, per ASPR 9-203."

DoD Imposed Distribution Statements (*reference DoD Directive 5200.20*) "Distribution Statements (*Other than Security*) on Technical Documents," March 29, 1965.

**STATEMENT NO. 1** - Distribution of this document is unlimited

**STATEMENT NO. 2 (UNCLASSIFIED document)** - This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of (*fill in controlling DoD office*).

(CLASSIFIED document) - In addition to security requirements which must be met, this document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval (*fill in controlling DoD Office*).

**STATEMENT NO. 3 (UNCLASSIFIED document)** - Each transmittal of this document outside the agencies of the U. S. Government must have prior approval of (*fill in controlling DoD Office*).

(CLASSIFIED document) - In addition to security requirements which apply to this document and must be met, each transmittal outside the agencies of the U. S. Government must have prior approval of (*fill in controlling DoD Office*).

**STATEMENT NO. 4 (UNCLASSIFIED document)** - Each transmittal of this document outside the Department of Defense must have prior approval of (*fill in controlling DoD Office*).

(CLASSIFIED document) - In addition to security requirements which apply to this document and must be met, each transmittal outside the Department of Defense must have prior approval of (*fill in controlling DoD Office*).

**STATEMENT NO. 5 (UNCLASSIFIED document)** - This document may be further distributed by any holder only with specific prior approval of (*fill in controlling DoD Office*).

(CLASSIFIED document) - In addition to security requirements which apply to this document and must be met, it may be further distributed by the holder ONLY with specific prior approval of (*fill in controlling DoD Office*).

11. **SUPPLEMENTARY NOTES:** Use for additional explanatory notes.

12. **SPONSORING MILITARY ACTIVITY:** Enter the name of the departmental project office or laboratory sponsoring (*paying for*) the research and development. Include address.

13. **ABSTRACT:** Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as (TS), (S), (C), or (U).

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. **KEY WORDS:** Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, roles, and weights is optional.

## RECOMMENDATIONS

Scan laser heating is recommended for infrared non-destructive testing applications where excessively long heating times would be required if conventional methods were to be employed to obtain thermal contrast. The technique is particularly applicable to the testing of large specimens where uniform specimen heating is difficult to achieve, or where the configuration requires that the heat source and thermal imager be positioned on the same side of the specimen.

## SUMMARY AND CONCLUSIONS

The development of scan-laser heating provides an effective method for uniform heating of specimens which can be inspected by thermal imagery. This technique provides a real time nondestructive testing capability for a variety of materials and structures such as bonded honeycomb structures.

In order for the two-dimensional scan laser technique to have maximum versatility as a heat source for infrared nondestructive testing, it was necessary to allow for adjustment of scan speed, vertical and horizontal beam travel, and scan line spacing. In addition, safety precautions are necessary in all applications to insure that personnel are not subjected to burns by direct or reflected invisible radiation from the CO<sub>2</sub> laser. The addition of a coincident visible beam from a low power laser was found to be beneficial in adjusting all scanning parameters, and determining the location of the invisible laser beam.

From results obtained in the laboratory, it can be concluded that scan laser heating is a valuable tool for infrared nondestructive testing of composite or bonded structures which have a thermally insulative outer surface over a thermally conductive core. Under these favorable conditions, it is possible to resolve defects as small as .95 cm on the thermal imaging display. The scan laser heating technique, however, does not show promise for real-time front surface heating for thick specimens or those with a thermally conductive outer surface over a thermally insulative core.

Solid metal specimens are much more difficult to evaluate. Here, the heat tends to be distributed evenly throughout the specimen and all thermal gradients caused by a subsurface defect are rapidly lost if indeed they ever appear at the surface. However, since the scan laser heating technique does offer a method for real time NDT, it could be advantageously employed for many structures, and warrants further study.

## EQUIPMENT DESCRIPTION

The basic equipment may be divided into four broad categories for consideration: a. laser, b. beam positioner, c. thermal imaging system, and d. safety equipment.

### a. Laser:

The laser employed in this evaluation was a Coherent Radiation Model 42 CO<sub>2</sub> with a 50 watt CW output. The beam diameter was 6.3 mm with a 2.2 mr beam divergence. The laser head is shown in Figure 1. It consists of a water-cooled glass plasma tube and an optical resonator. The laser medium is a continuous flowing mixture of nitrogen, helium, and carbon dioxide. The gas flows to the middle of the plasma tube and is pumped out the ends as shown in Figure 2. The total pressure in the tube is maintained at 25 to 35 mm of mercury.

The laser power supply controls the laser gas supply, water supply and electrical power. These are located in a cabinet which is safety interlocked. An umbilical tube connects the power supply cabinet to the laser head. The laser beam control circuit supplies a constant current to each of the two laser tube cathodes, and switches the laser beam current for precise on and off control.

### b. Beam Positioner:

The laser beam positioner normally scans the 50 watt CO<sub>2</sub> laser beam in a rectangular raster format. The complete positioner consists of an optical unit and an electronic control unit. It is designed to scan a wide variety of area patterns over a field of view of variable size at widely adjustable scan rates.

The optical unit of the beam positioner is shown in Figure 3. For safety purposes, a visible wavelength laser (Ne-He) is used to illuminate the area irradiated by the CO<sub>2</sub> laser. This is accomplished through the use of a dichroic element which permits the axial combination of the 6328A NeHe laser radiation and the 10.6 micrometer CO<sub>2</sub> laser radiation. The two beams meet at the dichroic element and form a scan pattern by the two scan mirrors shown. Small torquers drive the first surface scanning mirrors. One mirror scans the coincident laser beams in the X direction, and the other produces scanning in the Y direction. The torquers follow the waveform of the driving signal voltage and can be offset by an amount proportional to any DC voltage.

The beam positioner control unit, Figure 4, consists of two independent but synchronized electronic waveform generators. These operate individual driver amplifiers, one for each scan mirror. The electronic control also contains the on-off and scan start switches as well as adjustments for frame time and line resolution. A pulse output is provided that permits the CO<sub>2</sub> laser to be turned off during vertical retrace of the scanner.

Electrical modulation of the X and Y scan signals can produce a scan pattern of almost any desired shape for variable target coverage to 20° with a scan sweep speed up to 40 Hz. Figure 5 illustrates a rectangular scan normally employed for specimen heating. Figure 6 shows the scanner versatility by generating a circular scan.

#### c. Thermal Imaging System:

The thermal imaging system is an AGA "thermo-vision" as shown in Figure 7. The equipment consists of an infrared camera and an oscilloscope which displays the thermal image on its screen. A recording camera attachment allows permanent photographic records to be taken while the screen is being viewed. In the normal mode of operation, the thermogram displayed is a picture of the object viewed in a continuous range of gray tones, with a warm area appearing lighter than a cold area.

d. Safety Equipment:

The direct or reflected laser beam is capable of igniting materials or causing serious eye or skin burns, and care must be exercised to prevent unwanted exposure of materiel or personnel. Since plexiglas is an efficient absorber of the 10.6 micrometer laser radiation, it becomes a convenient visually transparent material for the fabrication of laser safety goggles and instrument covers (Figure 8). An additional 1.2 m x 2.4 m plexiglas sheet mounted on a movable stand is also used for protective screening.

The high voltage power supply necessary for operation of the laser also constitutes a potential safety hazard. The power supply cabinet and scanner controller cabinets contain interlock circuits to prevent accidental access to the electrical connections while operating. The door of the controlled access laser area also contains electrical switches to activate warning lights when the laser power supply is energized.

## TEST SPECIMENS

A variety of materials and structures was used in the evaluation of the laser scan heating technique for the detection of sub-surface defects:

### A. Honeycomb Structures:

1. Titanium skin, aluminum honeycomb aircraft structure. This structure was 1.9 cm thick. The outer titanium skin was 0.05 cm, and the honeycomb hexagon structure was .32 cm.

2. Fiberglass skin, phenolic honeycomb structure. This structure was 1.27 cm thick. The outer fiberglass skin was .32 cm, and the honeycomb structure was .95 cm hex. Circular disbond areas were created in preparing the panel. These were 5.08 cm, 3.81 cm, 3.18 cm, 2.54 cm and 1.91 cm in diameter. Figure 9 illustrates the arrangement of simulated defects in the bonded specimen.

3. Fiberglass skin, paper core structure. The structure was 3.81 cm thick. The outer skin was .32 cm thick, and the wave configuration paper core had a .64 cm wave to wave spacing. Disbond areas consisting of circular unbond areas 5.08 cm x 6.35 cm were also used to simulate defect areas.

4. Fiberglass skin, aluminum honeycomb core. The structure was 3.81 cm thick. The outer skin was .32 cm thick, and the honeycomb had a .95 cm hexagonal cell. Circular unbond areas were created in fabricating the structure. These were 5.08 cm, 3.81 cm, 2.54 cm and 1.91 cm diameter.

### B. Metal Structures:

#### 1. Solid Aluminum Panel

A 2.54 cm section of aluminum 30.5 cm square .32 cm, .64 cm and .95 cm holes drilled parallel to and .32

cm to .64 cm beneath the surface. These were used to simulate various size voids beneath the surface.

## 2. Bonded Aluminum Panel

An aluminum sandwich structure was constructed of a .64 cm aluminum plate sandwiched between aluminum plates .32 cm thick. 3.81 cm, 2.54 cm, 1.91 cm and .64 cm holes were drilled in the .64 cm plate to simulate voids, and the entire sandwich was bonded with two part epoxy adhesive.

## C. Other Specimens:

### 1. Tank Track Pads

A tank track pad which consists of approximately 5.08 cm of rubber bonded to a .32 cm steel base was used as a typical automotive component requiring nondestructive testing.

## EXPERIMENTAL PROCEDURE

Test specimen structures were painted to increase absorptivity of the laser radiation and to provide some uniformity in the comparison of various specimens. A specimen-to-laser distance of 4 meters was maintained for the investigation. This allowed an area up to 1.4 meter x 1.4 meter to be covered with the scan laser. The infrared camera head was placed 4.65 meters from the specimen. At this distance, a thermal image of an area .36 m by .46 m could be obtained.

Prior to activation of the CO<sub>2</sub> laser scan, the visible beam from the neon helium laser was used to establish the desired scan pattern. Horizontal and vertical scan distances were adjusted to cover the specimen without extensive overlap. The speed of scan was also selected to provide the desired degree of heating for each type of specimen examined.

The thermal image of the heated specimen was observed, and photographic records were made of the specimens under test.

## RESULTS

Figure 10 illustrates the thermal imagery obtained with scan laser heating of a fiberglass skin aluminum honeycomb structure. The defects, which are unbonded areas, range from 1 cm to 5 cm in diameter. The hexagonal cell structure was 1 cm. These defects were readily seen under a wide variety of scan speeds and laser beam power. Similar results were obtained with other fiberglass/aluminum structures.

A section of an aircraft panel consisting of .05 cm titanium skin over 1.9 cm aluminum honeycomb was also examined. Figure 11 shows a defect caused by de-bonding the skin from the core. In this case, photography of the thermovision screen enhanced the detection of the defective area since the rapid dissipation of heat in